A NEW PROCESS AND APPARATUS FOR RAPID AND HOMOGENEOUS MIXING OF FLUIDS IN CONTINUOS OPERATIONS

Field of the Invention

The present invention relates to all industries where the mixing of two fluids are needed, e.g. industry of aeronautics and aerospace, automobile, combustion, petroleum and chemical industry, food industry, pharmaceutical industry, biotechnology, polymer processing, mining industry, environmental engineering, naval industry, heat ventilation and air condition, power plant, measuring instruments and so on, and more particularly to a new process and apparatus for rapid and homogeneous mixing of fluids in continuous operations.

Background of the Invention

Traditional mixing processes are either based on the mechanism of fluid mechanics (producing shear layer, e.g., mixing layer, jet and wake) or mechanical process (agitated tanks). There are some flow control methods used to control the mixing. These can be either passive controls (static mixers) or active controls (initial disturbance of mixing layer, jet and wake through actuators).

These passive controls may use a vortex generator or other devise to change the fluid flow for mixing enhancement (e.g. motionless mixers). These active controls focus on the initial control of the Kelvin-Helmholtz vortices (jet and mixing layer) and Karman vortex street (wake) based on traditional flow instability (or receptivity) theory. Therefore agitated tanks do not belong to the active control.

For control based on traditional receptivity, the forcing frequency and amplitude are important parameters. The forcing frequency used to enhance mixing increases with fluid convection velocity. If the forcing amplitude is sufficiently high, increasing the forcing

amplitude will have no influence for the mixing enhancement because of its saturation phenomenon. This is the reason that the mixing enhancement due to the traditional forcing is limited, e.g. usually the shear layer spreading rate of a mixing layer approximately doubles that of an unforced mixing layer.

Traditionally it has been assumed that the high turbulent intensity can achieve intensive mixing. The high turbulent intensity will be produced through mechanical agitation, which needs a great amount of energy (e.g. agitated tanks), or through free shear flows (jet, mixing layer and wake), whose mixing rate is not high enough for many situations. Although there is some active forcing for free shear layers, the principle is based on the two-dimensional primary inherent instability mechanism.

Furthermore with mechanical forcing, the agitated mixers often use too much energy in order to achieve better mixing and there is often a dead region for mixing so that the quality of chemical products becomes low, and so does the mixing efficiency. The process costs more money due to inefficiency. Furthermore in the biotechnology area, cells can be destroyed by too strong shear stress near blade surface. With resulting chemical reactions, the product quality can be affected due to the approximate exponent residence time distribution.

Moreover, mixing through the jet, mixing layer, wake, with motionless and static mixer can be too slow. Large weight combustion or mixing chamber in engines are therefore required. All these flows have a large range of different scalar structures (scales), which make the modeling of the mixing much more complicated especially when there is chemical reaction. Direct losses in USA chemical processing industries alone, due to the problems of mixing, are estimated at $10 billion a year.

Prior art mixing processes have been devised to address some of the aforenoted problems. U.S. Patent No. 4,257,224 issued March 24, 1981 to Wyganski discloses a method and apparatus for controlling the mixing of two fluids in which an active element is

driven to induce, in the vicinity of the beginning of the mixing region, oscillations of the two fluids about an axis substantially normal to the mixing region flow axis.

U.S. Patent No. 3,408,050 issued October 29, 1968 to Jacobs discloses an in-line fluid mixing device comprising of an orifice and a blade-like vibratory element fixed at one end and disposed in line with the orifice so that the free end of the vibratory element is disposed opposite and closely spaced from the orifice.

There has also been some work on three-dimensional forcing for the mixing layer, but no specific forcing frequency has been discovered, which is insensitive to the average convection velocity of the two fluids streams, and under which there is no traditional saturation phenomenon of forcing amplitude when the forcing amplitude is sufficient high and the forcing influence on mixing enhancement strongly depends on forcing amplitude; and under which the mixing rate is extraordinarily rapid. Therefore, the mixing enhancement for traditional active forcing is limited.

Thus a process and apparatus for rapid and homogeneous mixing of fluids and creating streamwise vortices in continuous operations which overcomes the obstacles outlined above is desirable.

Summary of the Invention

An object of one aspect of the present invention is to provide an improved process and apparatus for rapid and homogeneous mixing of fluids and creating streamwise vortices in continuos operations.

The principle of the new mixing process can be shown as follows. It is based on a new receptivity. The new invention uses both, new passive and active controls of fluid flow to achieve an extraordinary rapid and homogeneous mixing of fluids. The active forcing not only enhances the primary vortices due to the primary inherent instability, but

also the secondary streamwise vortices due to a secondary instability mechanisms, e.g. the instability of streamwise vortices resulting from the interactions of streamwise corner vortices leaving the trailing edge between splitter plate and the side wall, and the primary spanwise vortex.

These streamwise vortices play an important role in the mixing enhancement. The periodic forcing contributes to the unstable flow because of the instability mechanisms in the viewpoint of receptivity to enhance the development of the initial disturbance. Under a narrow specific forcing frequency band, the dynamics of the streamwise vortices are very sensitive to the forcing amplitude and no traditional saturation of forcing amplitude exists. Thus the forcing can result in an extraordinarily rapid mixing, where the spreading angle of the shear layer can be 180°. The narrow specific forcing frequency band is not scaled with the average convection velocity of the two streams. This makes the operation more flexible and the corresponding apparatus have more applications.

The flows based in the new invention for mixing are three dimensional shear flows (shear layers, quasi-step flow when one stream velocity is zero or wake), which through the geometry of confinement of the flow in the mixing chamber, are overlapped with the streamwise vortices. The enhanced mixing process is initiated first through the primary and secondary vortices.

Through these instability mechanisms, the initial disturbance will in the flow be amplified to a maximum under some specific frequency (which does not scale with convection velocity). Meanwhile, downstream of the trailing edge, the spanwise primary vortices and the streamwise vortices are induced downstream of the trailing edge and amplified extremely fast. The confined configuration, or the corners between the splitter plate and side wall or the non-homogeneity of the splitter plate in spanwise direction can enhance the inducement of the streamwise vortices and the corresponding three dimensionality of the fundamental flow.

The fast amplified streamwise vortices break down the primary structures very rapidly, and then produce very small structures embedded in the large structures and thus result in the rapid mixing of the two streams finally. The amplification of the streamwise vortices, e.g. the corner vortices strongly depends on some narrow specific forcing frequency band and its corresponding forcing amplitude. This is essential for the new invention. The optimal amplification of the initial disturbance and its corresponding rapid mixing process depend therefore strongly on the forcing frequency, i.e. only for a narrow specific forcing frequency band, can the mixing be strongly enhanced. This is important for the fast mixing in small Reynolds number flows, where the mixing is slow by other mixing process.

In this new mixing process, the modern passive and active control is effectively used. Advantages of the present invention are: due to the very high receptivity, the input energy is optimally transferred to small scales from large scales so that the achieved mixing enhancement and efficiency is clearly much higher than others used; since the mixing is extremely rapid, the length of mixing chamber can be reduced. This can conserve the weight and space of engines of flights; the mixing chamber is fully used; no dead and/or back flow region exists; since no blade is used, the problem with cell breaking can be mitigated; the installation of the mixer and its construction is simpler; the process is in continuous operations; it is easier to control the mixing and temperature; when used for a chemical reactor, the scaleup would be easier, due to the fact that (1) the scale of the two fluids is more homogeneously distributed because of the possibility of the control of the small structures and therefore the reactor modeling can be more accurate; (2) if more tubes of experimental size are used for industrial scale, some scaleup problems would be bypassed.

Brief Description of the Drawings

A detailed description of the preferred embodiments are provided herein below by way of example only and with reference to the following drawings, in which:

Figure 1 is a schematic view, illustrates mixing apparatus in accordance with the preferred embodiment of the present invention;

Figure 2a-c in side views, illustrate the mixing results for three different situations of a mixing layer of the preferred embodiment of figure 1.

In the drawings, preferred embodiments of the invention are illustrated by way of example. It is to be expressly understood that the description and drawings are only for the purpose of illustration and as an aid to understanding, and are not intended as a definition of the limits of the invention.

Detailed Description of the Preferred Embodiment

Referring to figure 1, there is illustrated in a schematic view, an apparatus for rapid and homogenous mixing of fluids in continuos operation in accordance with a preferred embodiment of the present invention. The new invention uses passive control to provide a favorable condition (i.e. enhance the streamwise vortices) for the active control to enhance the mixing of fluids.

The mixing process and its corresponding apparatus are as follows. The new mixing process is under continuous operations. The mixing chamber consists of one or more tubes having a proximal end and a distal end or backward step. The tube can be different geometry of cross section, e.g. round, rectangular, square, triangle and so on. In

each tube, there is at least one splitter plate in the inlet, which separates the two streams of fluids, which are to be mixed. The splitter plate can be designed as straight or wave-form to enhance the streamwise vortices.

The two fluids come to the mixing chamber through the different side of the splitter plate and meet each other directly downstream of the trailing edge of the splitter plate. If the two streams meet through annular mixing region, some extra splitter plates should be added to produce corner vortices. The initial two streams of fluids can parallel or by an angle meet each other at the trailing edge. The average velocity of the two streams can be the same (wake) or different (mixing layers or quasi-step flow when one stream velocity is zero).

The mixing process can also be used for one stream flow (e.g. premixed flames in combustion), where the mixing of fluids from different spatial positions with different properties (e.g. residence time, temperature and concentration and so on) is required.

The flow in the mixing chamber can be unforced or forced. The impetus influence (forcing) can be active (through external input of energy) or passive (through the flow self-induced energy or self-excited oscillation). The forcing aims to enhance the unstable vortices waves for mixing enhancement. Through the suitable forcing, an extraordinary rapid mixing of the two streams can be achieved directly downstream of the splitter plate. This effect can be stronger if the temperature or density of the two streams is different.

In some cases, when the velocity difference of the two streams is sufficiently high, and the average velocity is also sufficiently high, and tube size is sufficiently small, the mixing is also very fast without active forcing. In these cases, the high speed side fluid flows to the low speed side in the middle part and the low speed side fluid flows to high speed side along the wall regions. Such a secondary flow and the streamwise vortices can enhance the mixing very rapidly and the active forcing may not be necessary.

In operation the mixing apparatus as shown in figure 1 shows the apparatus of the mixing process. The periodic disturbance can be realized through a vibrating trailing edge or through periodic fluctuation of one stream, e.g. over a piston-/membrane mechanism or through a membrane forced by a loudspeaker or a temporal variable flow resistant in one of the two streams. The two streams, one of which is dyed, meet each other downstream of the trailing edge at the beginning of the whole tube length, i.e., the mixing chamber. The flow can be visualized through laser induced fluorescence.

Figure 2 shows the visualized mixing results from the side view for three different situations of a mixing layer with initial two streams of different velocity U1 = 30 and U2 = 20 cm/s respectively. Figure 2a shows the flow in an unforced mixing layer and that the mixing is poor. Figure 2b shows the flow actively forced under traditional instability mechanism. The mixing is enhanced compared with the case of figure 2a and the mixing spreading rate of the shear layer approximately doubles that in Figure 2a.

Figure 2c depicts how the flow is periodically forced through the new instability mechanisms. This corresponds to the new mixing process. The mixing is now, when compared with the other two situations, i.e. Figure 2a and Figure 2b, on the whole, a completely different quality. The homogeneity of small structures of the two streams over the whole cross-section of the mixing chamber is already achieved clearly just downstream of the trailing edge. The spreading rate of the shear layer is approximately 180°, i.e. the limitation of the possible maximum value.

The rapid new mixing process is useful in processes with rapid chemical reaction. Besides improved fluid mixing, the rapid mixing process has several other applications, one of which is the reduction of acoustic noise. In many industries, silencers must be used to enhance the fluids mixing while abating the jet noise and/or shift its frequency to a less disturbing range.

Another application is to improve the reactor instability. One example is combustion instability, e.g. flame instability and so on. In most cases, the combustion instability is related to the mixing of fuel and oxidant (e.g. air). If the mixing is enhanced, the combustion process can become more stable.

Another application is in the reduction of the flow separation. Since the large-scale mixing process can transfer high momentum from outer layer or free streams to low momentum fluid of the inner layer flow, the present invention can reduce the flow separation. Another application is for heat transfer enhancement.

Other variations and modifications of the invention are possible. All such modifications or variations are believed to be within the sphere and scope of the invention as defined by the claims appended hereto.